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(54) APPARATUS FOR DETECTING CARBON DIOXIDE

(71) We, DRAGERWERKE AKTIENGESELLSCHAFT, a German body corporate, of Koislinger Allee 53/55, Lubeck, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the detection of gases, and more particularly is concerned with the detection of carbon dioxide.

Closed-circuit respiratory systems, to which for example a patient or a person taking part in an experiment is connected by means of a breathing valve or the like so that the exhaled air flows into the system but is subsequently inhaled again from the said system, are known in medicine for various purposes. Thus the breathing air circulates through a closed-circuit respiratory system of this kind, directed by valves. Due to the gas metabolism processes in human beings oxygen is taken from the system whereas carbon dioxide is discharged into the system. The oxygen is continually supplemented from the outside, and the carbon dioxide is fixed by absorbers which are interposed in the system. These absorbers are generally pots with a filling of soda lime or similar substances, which contain substantially CaO and NaOH, i.e. have an alkaline reaction and are capable of absorbing a specific volume of CO_2. When the soda lime supply is saturated with CO_2, it is thrown away, and the absorbers have to be charged with fresh lime. However, the instant of exhaustion is uncertain. It is true that the substance commercially available as respiratory apapratus lime contains an indicator which is intended to indicate the instant of exhaustion to the doctor by means of colour change, but the colour change is based not on carbonate formation but on increasing moisture content. This moisture increase, normally due to the water produced as a reaction product of the fixing of CO_2, may however be due to other causes such as formation of water of condensation from the exhaled air. On the other hand, the respiratory apparatus lime sometimes loses during storage a considerable proportion of the moisture (desired value about 15%) which was added to it by the manufacturer, so that the reaction water is no longer adequate to bring about a colour change. Whereas in the first-mentioned case the respiratory apparatus lime filling is replaced too often, which involves unnecessary expense and work, the last-mentioned case represents a danger to the patient since he inhales carbon dioxide again, which leads to a dangerous pH shift in the blood (so-called acidosis).

The inadequacies of respiratory apparatus lime are generally adequately known to doctors, particularly anaesthetists, who work as a matter of routine with closed-circuit respiratory systems (e.g. anaesthetising systems). Here, for safety reasons, two absorbers are placed in series, changing them round and replacing them alternately. Thus, some inconvenience must be tolerated if it is desired to work with respiratory apparatus lime in an even moderately economical manner whilst maintaining adequate safety for the patient.

Therefore, the desire to have a CO_2 warning apparatus is probably as old as closed-circuit respiratory systems themselves, but an apparatus of this kind would have to be small, robust and inexpensive if it is to be suitable for routine work, which presupposes a very simple measuring principle.

Manual chemical analysis process are often too laborious to carry out, and the apparatus which use physical gas properties (e.g. infra-red gas analysers) are too large and involve too much outlay in every respect. The relatively simple thermal conduction process is also not suitable since it operates in a non-selective manner whereas the breathing gas concentration in the closed-circuit system may vary very considerably in composition.

Therefore a search had to be made for

a process which uses a special feature of CO_2 for measuring purposes which otherwise is not characteristic of any of the gases present in the carrier gas mixture of closed-circuit respiratory apparatus systems.

The underlying idea of this invention proceeds from the realisation that of the gases present in the gaseous mixture only carbon dioxide dissociates in aqueous solution and thus leads to a modification of the electrolytic conductivity of an aqueous solution.

Apparatus which determine the concentration of reactive gases in suitable electrolytes in a similar manner are known *per se* in many constructional forms. They are, for example, referred to as "Ionoflux" apparatus (Messrs. Hartmann & Braun A.G., Frankfurt/M) and are used particularly for the trace analysis of H_2O, H_2S, SO_2, NH_3, NO_2 and other gases, wherein there is used as reactant in each case a suitable solution which absorbes the measurement gas component. As a rule the electrolytic conductivity decreases in the reaction. This modification of conductivity is electronically processed and made indicatable.

This is in fact a very simple measurement principle but the apparatus of this type are very large. This is due to the several litres of electrolyte supply which are necessary and likewise a large collecting container for the discharged electrolyte. In addition apparatus are provided for ensuring constant flow of electrolyte and measurement gas. Naturally, these apparatus must not be capable of being knocked over, and are therfore only suitable for substantially fixed-location use.

According to one aspect of the present invention there is provided an apparatus, for detecting carbon dioxide in a gaseous mixture which has passed through an alkaline absorber in a closed circuit respiratory system for a patient, which comprises a cell of a size such that it can be located in a tube which supplies said gaseous mixture from said alkaline absorber to the patient, the or a wall of which cell includes at least one membrane which is gas-permeable and liquid-impermeable and which is such that, when located in said tube and in use, the outer surface of said membrane contacts said gaseous mixture, wherein the cell contains two spaced electrodes which are immersed in deionised water and which are, or are adapted to be, connected to means for determining the electrical conductivity of liquid which, when the apparatus is in use, occupies the space between the two electrodes.

According to a further aspect of the invention, there is provided a closed circuit respiratory apparatus which comprises an alkaline absorber for absorbing carbon dioxide present in a gaseous mixture passing through the apparatus and a tube which, in use, supplies the gaseous mixture from the alkaline absorber to a patient, wherein said tube contains a cell the or a wall of which includes at least one membrane which is gas-permeable and liquid-impermeable, and wherein said cell contains two spaced electrodes which, in use, are immersed in deionised water and which are, or are adapted to be, connected to means for determining the electrical conductivity of liquid which, when the apparatus is in use, occupies the space between the two electrodes.

In contrast to the known procedures, the present invention proceeds from the idea of using as electrolyte fully desalted (i.e. deionised) water which, after reaction has occurred, can be regenerated again as required through the agency of a small supply of ion exchanger (e.g. mixed bed filter) substance which may be situated in the apparatus. A reaction path such as is characteristic of the "Ionoflux" apparatus is not used, since gas exchange is effected through the agency of a gas-permeable membrane or diaphragm, for which some plastics material sheetings such as, for example, silicone rubber, polyethylene, copolymers of tetrafluoroethylene and hexafluoropropylene and polytetrafluoroethylene (e.g. "Teflon"—Registered Trade Mark) and others are suitable.

The change in conductivity, which in the case of the present invention will be an increase, when CO_2 is present in the gaseous mixture reaches a value which corresponds to the solubility equilibrium between gas and liquid phase. The vessel is preferably constructed so that it can accommodate only a very small quantity of water, so that the gas exchange operation through the diaphragm reaches a final value as quickly as possible.

Because in use the measurement cell is filled with fully desalted water, the measuring cell is of very high electrical resistance. With a comparatively low-resistance indicating instrument, this produces in the diagonal of a Wheatstone alternating-current measuring bridge a high zero point stability, whereas even CO_2 concentartions of the order of magnitude of 0.05% lead to a considerable conductivity increase in the solution and therefore a powerful measurement effect. The same effect, of course, can also be simulated electrically by connecting a high-ohmic resistance in parallel with the measuring cell, this resistance being adapted to be actuated from the outside by means, for example, of a test pushbutton. The amount of the deflection at the indicating instrument is a measure of the high-ohmic resistance of the measuring cell, which corresponds to a sensitivity control of the apparatus. This kind of operational

control, which is connected directly with the sensor in a physically correct manner, is an indispensable requirement more particularly for routine measuring apparatus.

The interchanging of the electrolyte in the measuring vessel, which is necessary whenever monitoring shows too small a resistance at the cell, is preferably effected by operating a pump mechanism, for example a normal injection syringe, which is accessible from the outside. The cell, which is generally connected through the agency of flexible hose connections on the one hand with the syringe and on the other hand with a supply vessel containing an ion exchanger, is preferably washed and freed of any gas bubbles. An air cushion in the supply vessel can advantageously ensure that, with this pump arrangement, a liquid line is reached which is closed off in sealing-tight manner relative to the atmosphere. Thus the result is achieved that the apparatus can be transported in any position and without precautionary measures.

For a better understanding of the invention, and to show how the same can be carried into effect, reference will now be made, by way of example, to the accompanying drawing, which shows one embodiment of the present invention.

The operating voltage is branched from, for example, the alternating-current lighting mains by way of a voltage divider (R1—R2—R3—R4) or from bateries by way of an inverter. (R2) and (R3) at the same time form two branches of a Wheatstone bridge, which is supplemented by (R5) and (R6). (R5) is used for zero adjustment, and (R6) is the detecting cell. The resistance (R7) adapted to be connected-in in parallel with (R6) by means, for example, of a pushbutton is used for monitoring the high-ohmic resistance of the cell (sensitivity control). The cell (R6) consists in principle of two electrodes (6a and 6b) which are arranged with small spacing from one another and are made of, for example, non-rusting steel or another suitable metal with a common envelope comprising a diaphragm of plastics material (9) with good diffusible gas-perviousness (e.g. silicone, polyethylene, "Teflon" (Registered Trade Mark) or the like). The cell is provided at both ends with unions (10, 11) which serve for washing and filling with electrolyte (deionised water) through the flexible hose connections (12, 13). Washing is effected by means of a pump (14) which here is in the form of an injection syringe. The supply of electrolyte (15) is situated in a vessel (16) which contains a mixed bed ion exchanger substance for full desalting or regeneration of the electrolyte. The indicating instrument used in this embodiment is a galvanometer (18) which, through the agency of a diode (19), indicates variations in the electrical symmetry of the measuring bridge. The cell (R6) is arranged in a tube with two terminal screw-hreaded portions (20, 21), through which tube the gas for measurement flows and by means of which a connection into the main gas flow of closed-circuit respiratory system is possible.

Measuring and recording devices and/or controlling or limit contact signalling devices may be incorporated into the apparatus of the invention. In addition, one or more filters, absorption or reaction paths may be provided for the gaseous mixture which is to come into contact with the detecting cell.

In one embodiment of the invention, the detecting cell is adapted to be used immersed in a liquid in which carbon dioxide is dissolved.

WHAT WE CLAIM IS:—

1. An apparatus, for detecting carbon dioxide in a gaseous mixture which has passed through an alkaline absorber in a closed circuit respiratory system for a patient, which comprises a cell of a size such that it can be located in a tube which supplies said gaseous mixture from said alkaline absorber to the patient, the or a wall of which cell includes at least one membrane which is gas-permeable and liquid-impermeable and which is such that, when located in said tube and in use, the outer surface of said membrane contacts said gaseous mixture, wherein the cell contains two spaced electrodes which are immersed in deionised water and which are, or adapted to be, connected to means for determining the electrical conductivity of liquid which, when the apparatus is in use, occupies the space between the two electrodes.

2. A closed circuit respiratory apparatus which comprises an alkaline absorber for absorbing carbon dioxide present in a gaseous mixture passing through the apparatus and a tube which, in use, supplies the gaseous mixture from the alkaline absorber to a patient, wherein said tube contains a cell the or a wall of which includes at least one membrane which is gas-permeable and liquid-impremeable and wherein said cell contains two spaced electrodes which, in use, are immersed in deionised water and which are, or are adapted to be, connected to means for determining the electrical conductivity of liquid which, when the apparatus is in use, occupies the space between the two electrodes.

3. An apparatus as claimed in claim 1 or 2, wherein said closed circuit respiratory system or apparatus is an anaesthetising system.

4. An apparatus as claimed in claim 1,

2, or 3, wherein said membrane is made of a plastics foil.

5. An apparatus as claimed in claim 4, wherein said plastics foil comprises a silicone rubber, a polyethylene, a copolymer of tetrafluoroethylene and hexafluoropropylene, or polytetrafluoroethylene.

6. An apparatus as claimed in any preceding claim, which further comprises a receptacle in communication with said cell and containing or being adapted to contain an ion exchanger and deionised water.

7. An apaparatus as claimed in claim 6, wherein said ion exchanger is a mixed bed ion exchanger.

8. An apparatus as claimed in claim 6 or 7, which further comprises means for transferring deionised water across said cell into said receptacle, and *vice versa.*

9. An apparatus as claimed in claim 8, wherein the means for transferring deionised water is a pump.

10. An apparatus as claimed in claim 8 or 9, wherein the means for transferring deionised water is hand-operable.

11. An apparatus as claimed in any preceding claim, wherein the two electrodes of said cell are connected in an electrical circuit to form one arm of an alternating-current bridge.

12. An apparatus as claimed in claim 11, wherein said alternating-current bridge is provided with a high resistance and means for electrically conecting and disconnecting said high resistance in parallel with said cell.

13. An apparatus as claimed in claim 11 or 12, wherein the alternating current measuring bridge is provided with means for compensating errors arising fom the variety of environments in which the detection cell may be placed.

14. An apparatus as claimed in claim 13, wherein said means comprise one or more cells provided with a gas-permeable or gas-impermeable diaphragm.

15. An apparatus as claimed in claim 11, 12, 13 or 14, wherein the resistances in the alternating current bridge are provided with means for obtaining zero adjustment and sensitivity correction of the alternating current bridge.

16. An apparatus as claimed in any preceding claim, wherein measuring and recording devices and/or controlling or limit contact signalling devices are provided.

17. An apparatus as claimed in any preceding claim, wherein electrical curent is obtained from alternating-current mains or from batteries by way of an inverter.

18. An apparatus as claimed in any preceding claim, which further comprises one or more filters, absorption or reaction paths for the gaseous mixture which is to contact said cell.

19. An apparatus as claimed in any preceding claim, wherein said cell is adapted to be used immersed in a liquid in which carbon dioxide is dissolved.

20. An apparatus substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

21. A method of detecting carbon dioxide in a gaseous mixture which has passed through a alkaline absorber in a closed circuit respiratory system for a patient, substantially as hereinbefore described.

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1314877 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*